Width and Persistence of the Chukchi Polynya

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William J. Stringer

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Janis Zender-Romick

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Introduction

It has been long recognized that along the western Alaskan coast from Point Hope to Barrow, there is often a band of open water just offshore from the landfast ice. This opening in the ice is at times a well defined lead and at other times, a series of openings in the ice or polynyas. Here we have referred to this open water by the more general term, although at times it is definitely a well defined lead. This analysis has been performed in order to provide a statistical characterization of the width of this polynya and its variation over time.

This analysis is of interest to the Outer Continental Shelf Environmental Assessment Project (OCSEAP) from several points of view:

1) The polynya system offers an avenue for the transport of spilled petroleum for considerable distances along the coast.
2) Newly forming ice is available within the polynya which could incorporate spilled petroleum, thereby facilitating its long distance transport.
3) The open water of this polynya system is available to migratory waterfowl at times when pack ice conditions exist elsewhere. This study should help aspects of environmental assessment based on waterfowl behavior.
4) This polynya system is part of the migratory pathway used by whales returning to the Beaufort Sea in the spring. These results will be used as part of an overall assessment of the whale migratory pathways.

Data. Analysis

Six sites were chosen along the Chukchi coast between Point Barrow and Point Hope at which to perform measurements (see figure 1). At first it was planned to use Landsat imagery exclusively for these measurements because of its nominal 0.1 km resolution. However, estimates of the resulting data showed that more measurements would be necessary to provide an accurate reflection of the behavior of the polynya. For this reason, weather satellite imagery was employed as well. This imagery has a resolution of around .5 km.

Imagery of the study area is available from each Landsat on three days out every eighteen. Occasionally two satellites have been operated, doubling the frequency of coverage, although usually only one satellite has been operational at any given time. The meteorological imagery is available on a frequency as great as two to three times a day, although only one image is actually positioned such that reliably accurate measurements can be made. Both data sets are limited by cloud conditions greater than a single layer of stratus.

Rather than discard the use of the occasional Landsat image, it was found that when available, the Landsat imagery greatly enhanced the interpretation of features seen on the meteorological satellite images. Very often these features could be seen for periods of several days to a week. By this means, the Landsat imagery provided "calibration" of the measurements performed from the lower resolution meteorological imagery.

Landsat imagery is not available between 1 November and mid-February because of the absence of sufficient light. The visual band of the meteorological satellite is also limited by this condition. During the period for which satellite imagery was available (1974-1981), the meteor-

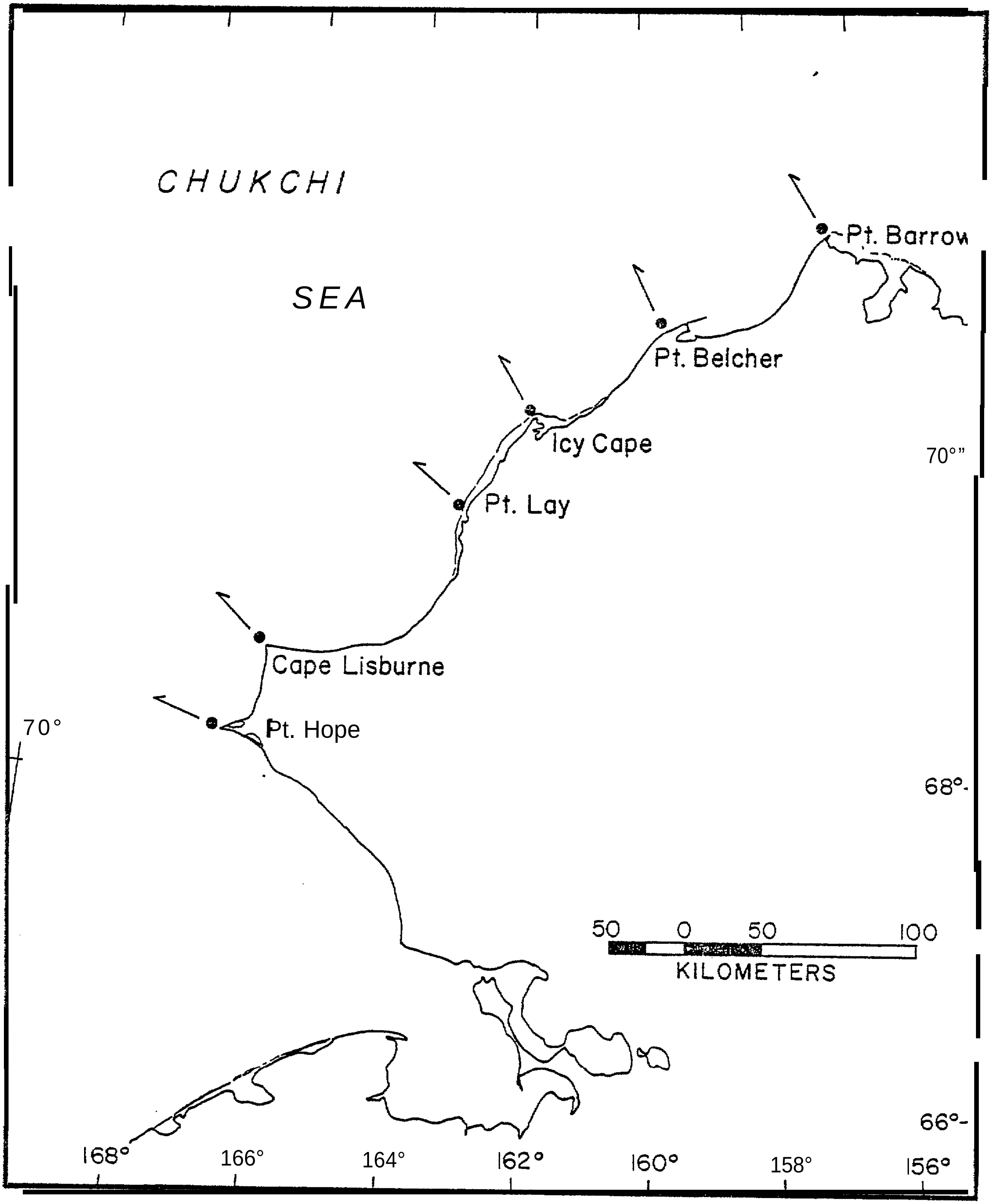

Figure 1. Map of Chukchi Sea coast of Alaska Showing locations at which Chukchi polynya width measurements were performed.

ological satellites normally employed a thermal band infrared imaging system as well as the visual band imager. The thermal imagery is usually of lower resolution than the visual band imagery. However, this is not the only problem encountered with the use of this data. The thermal imagery is considerably more difficult to interpret than the visual band imagery because the grey-scale values are generated by a combination of emissivity and temperature. This is complicated further by the tendency for leads to freeze to the "new" stage very quickly because of the low temperatures during the time that only thermal infrared imagery is available. Finally, without the occasional Landsat "calibration," image interpretation becomes progressively more unreliable. For these reasons, analysis was limited to the months of February through November.

The width of the Chukchi polynya was therefore measured at six points on all occasions possible for nine months out of each year for eight years. This provided approximately 13,000 possible measurements. Approximately 52% (6800) of these were obtained.

Results

Tables 1 through 6 summarize the results of the polynya measurements by location. The quantities listed on each line are explained below:

1) Average Width. Width measurements were averaged for each station for each month. Then the monthly mean widths were averaged. These values are listed here. It is immediately obvious that some of the average widths listed are smaller. than the resolution of the meteorological satellite imagery upon which the results are based. This is largely the result of averaging many zero width values along with small, but finite values. As will be seen from entries explained below, many of the width values averaged during these months were zero or so small as to be taken as zero. As a result, the average width values which are less than the meteorological satellite resolution of about .5 km are probably slightly smaller than they should be since small widths were taken as zero. However, this effect is probably not particularly significant.
2) Average Standard Deviation. The standard deviation was found for each month's width values. These standard deviations were then averaged over all eight years, Hence, the value listed is an indicator of the standard deviation which might be expected about the average width during an average month.
3) Extreme Maximum Width, This is the greatest width recorded during each month over the eight-year span of the study. These extreme values might be expected to be repeated or exceeded at approximately a 12% probability level during any given year.

4) Average Maximum Width. This is an average of the eight yearly maximum widths obtained for each month.

5) Average Minimum Width. This is an average of the eight yearly minimum widths obtained for each month.

6) Percent of calendar days with zero width. Each calendar day of the month was considered in turn. The fraction of days with at least one occasion when zero polynya width occurred was computed. This quantity was recorded for probability calculations.

7) Percent of occasions with zero width. Considering all the occasions when width measurements were possible during each calendar month over all eight years, this is the percent of those occasions when the poloynya had zero width. This is an important statistic to be used in the characterization of polynya behavior.

8) Percent of Occasions with Width >300 km. Considering all the occasions when width measurements were possible during each calendar month, this is the percent of those occasions when the polynya had a width greater than 300 km. (This is clearly a summertime measurement.)

9) Average percent of occasions when measurements were possible. This is the percent of occasions for each month over all the years of study for which measurements were possible.

These tables are compiled in order of month for each of the six stations from which measurements were made. While this is convenient for a station-by-station analysis, it does not provide a synoptic view of the polynya on a month-to-month basis. Before discussing the behavior of the polynya on a general basis, it worth while to extract the information required to construct a regional picture of the behavior of the polynya with time.

The monthly behavior can be described as follows:

a) February. The average width of the polynya is uniformly small (on the order of a few tenths of a km). The standard deviation is on the order of twice this value. However, extreme maximum values are on the order of twenty times the average width (on the order of 10km). At all six study locations, the polynya exhibited zero width on more than 70% of observed occasions.

b) March. The average width of the polynya is approximately twice its February width (on the order of .5 km). The standard deviation is again approximately twice the average width and the extreme maximum width is again on the order of twenty times the average width (10 to 15 km, except at Point Hope were all values are considerably smaller than elsewhere). At all six study locations, the polynya exhibited zero width on more than 65% of observed occasions.

c) April. The average widths of the polynya are all very close to 1 km (again twice its previous width). Continuing this doubling trend, the standard deviation values are also twice the March values (remaining approximately double the average width). The maximum observed widths lie between 13 and 20 times the average width (a weakening of the factor of 20 noted for the previous months). At all six study locations the polynya had zero width on more than 50% of observed occasions.

d) May. Starting at this time, the width of the polynya is less uniform than during the previous months. It is narrowest at its ends (3 and 6 km) and widest in the center (34 km at Point Lay). While at Point Barrow and Point Hope the standard deviations in width values are on the order of 1.5 times the average width, at

Point Lay the standard deviation is only half the width. The extreme maximum observed widths become more complicated, but continue to exhibit values, several times greater than one standard deviation. The percentage of zero width measurements varies from a maximum of 90% at Point Barrow to a minimum of 32% at Point Lay. In other words, the probability of the polynya occurring varies from a minimum of 10% at Point Barrow to a maximum of 68% at Point Lay.

e) <u>June.</u> The trend starting in May for the greatest average polynya widths to occur in its center continues (75 km at Point Lay}. However, the northern end average value (4 km) is considerably narrower than the southern end (58 km at Cape Lisburne). In general the standard deviation values are on the same order of magnitude as the width values while the extreme maximum width values have increased to a maximum of 370 km at Point Hope which is roughly six standard deviations from the mean value. At Point Barrow, the extreme maximum width of 50 km is eight standard deviations from the mean. The percentage of occasions of zero width also varies considerably, from a maximum of 47% at Point Barrow to a minimum of .7% at Point Lay, increasing back to 33% at Point Hope. Hence, by June the polynya is an almost absolute certainty (99.3% probability at Point Lay) .

f) <u>July</u>. The trend toward greatest polynya widths occurring in the center still continues. The smallest width value by far occurs at Point Barrow (average = 17 km) and the largest at Point Lay (141 km) . Cape Lisburne, now the southern end (with virtual open water at Point Hope), shows on average width of 70 km. The standard deviation values are now all equal to or smaller than the average values.

The maximum observed widths are now quite large (even 105 km at Point Barrow), being largest at Point Lay (400 km). The percentage of occasions of zero width still remains high (41%) at Point Barrow, decreases to 0% at Point Lay and increases to 3% at Point Hope.

g) August. The widening of the polynya increases dramatically (the average width becoming 50 km at Point Barrow). At Point Lay the average width is 306 km, while at Cape Lisburne and Point Hope, it is beyond measure by the methods used and actually is no longer defined. By this time, the strict concept of this body of water as a polynya probably ceases to apply, particularly to the south: whereas in July it was still closed on 2 and 3% of observed occasions at Cape Lisburne and Point Hope, it is now never observed closed at the southern end. The maximum width observed now becomes extremely large, varying from 240 km at Point Barrow to 545 km at Point Hope. However, even during this month, both Point Barrow and Point Belcher have had polynya widths of zero on 31% and 13% of occasions, respectively.

h) September. The average width becomes difficult to measure because the ice edge is often beyond the edge of the satellite image. However, sufficient quantities of values are so large that the average width can only be expressed in terms of numbers greater than a given width. At Barrow, the smallest average width, this value is 162 km, On some images values as high as 415 km were recorded for Barrow. During this time, the minimum width behavior becomes much more important than the average or maximum width. The tables show that at Barrow (but at no other point) on 8% of observed occasions there was no polynya. At Point Belcher, the minimum polynya width observed during September was 10 km. At Icy Cape it was 28 km, and at Point Lay it was 84 km.

i) October. We begin to see the result of the freezing of new ice. Although the average polynya widths remain too great for accurate tabulation, the minimum widths afford the best reflection of the advance of season. At Point Barrow, there was no polynya on 41% of all observations in this month, up from 8% in the previous month. Furthermore, where during September Point Barrow was the only location with any occurrence of no polynya, now this phenomenon continues down the coast: 32% at Point Belcher, 25% at Icy Cape, 19% at Point Lay, 6% at Cape Lisburne and 4% at Point Hope.

In summary, the following description of the synoptic behavior of the Chukchi polynya can be made:

1) Between February and April the average width is equal to or less than 1 km, During this time, the extreme widths observed range from a few km in February to 20 km in April. More than 50% of the time the polynya is closed during this period.

2) During May-June the polynya is considerably wider at the center than at its ends. The average northern width (about 4 km) in June is considerably smaller than the average southern width (58 km). The average center width in June is on the order of 75 km. During this period, large variations in width can occur (several times the average width). The polynya is virtually permanent: the fraction of time the center of the polynya is closed declines to 3%.

3) During July-August the polynya is actually open at the southern end 97% of the time (while open only 70% of the time at the northern end). The average width increases dramatically (50 km at the northern end, 300 km in the center) and extreme widths of several hundred km occur. The only stations where the polynya is ever completely closed during this period are Point Barrow (60%) and Point Belcher (20%). The other stations are constantly ice-free.

4) September is the period of maximum open water. No polynya as such exists. Occasionally (8% of the time) the pack ice is held against the coast at Point Barrow.

5) October is characterized by the freeze-back process. Still, no polynya exists. Average distances to the pack ice are very large. However, ice is found adjacent to the coast starting with maximum frequency at Point Barrow (41%) and diminishing down the coast to 4% at Point Hope.

It is worth noting that at all stations the average width increases with time through September and then decreases in October. No oscillations in average width were found for any station. This is taken to indicate that no sytematic changes in the general opening pattern occur.

The Chukchi polynya appears to occur as a result of the general trend toward westward ice motion seen in the Beaufort gyre. The motion of the gyre is not uniform, but tends to be least during the coldest months (Coon and Pritchard, 1979). However, the limited motion of the gyre is not the only reason that the Chukchi polynya is very small during these months: the extreme cold grows ice quite quickly. On

Landsat images from this period, successive seaward motions of the pack ice away from the Chukchi coast can be seen, recorded by parallel bands of successively younger ice attached to the pack ice as it receeds seaward. This newly generated ice tends to fill the polynya.

Landsat images were also examined which gave evidence that the general seaward ice motion had reversed, resulting in the closing of the polynya. Correspondingly, eastward motions of the Beaufort gyre and ice adjacent to this study area have also been recorded (Coon and Pritchard, 1979) .

A qualitative correlation can be found between the average ice motion away from the coast and the mean vector wind for all months except perhaps July: during early spring the mean vector wind is from the northeast along the Chukchi coast with magnitudes in the vicinity of 6 knots at Point Lay and slightly less elsewhere (Brewer, et al., 1977). These winds decrease with time and by July very low values are found. In August the northeast wind resumes with a magnitude of 1.5 knots at Point Lay. By October the Point Lay mean vector wind magnitude is 4.9 knots.

Implications to Offshore Environmental Assessment Considerations

There are several factors to be considered when examining the implications of this polynya on offshore environmental assessments. The Chukchi polynya usually occurs along the fast ice edge and is often located along the more shoreward of the statistical fast ice edge locations (see Stringer, 1980). This usually places the polynya in waters starting at depths of 15 to 20 m and deepening to the seaward. In general, the Chukchi coastal apron of fast ice is not nearly as extensive as its Beaufort counterpart. Finally, where under-ice currents in the Beaufort Sea are very low in velocity, they are more significant in the Chukchi region as a result of flow into the Arctic Ocean from the Bering Sea.

These factors combine in the Chukchi coastal region in the following way: because of the limited extent of fast ice here, it is likely that few offshore petroleum deposits will be located within the fast ice zone, Therefore, it is likely that any required offshore drilling structures and other facilities will be located within the zone of the Chukchi polynya. Because of the high degree of ice activity in this zone, it is very likely that spilled petroleum will (1) be incorporated into newly formed ice within the polynya, (2) be advected by currents to distant points within the polynya and perhaps even under the adjacent ice, and (3) be incorporated into ridges during those occasions when the polynya closes.

Because of the dynamic nature of ice activity here, operations conducted to clean up oil spills would be more hazardous than similar activities conducted in the Beaufort Sea. Because of this increased hazard, it is possible that clean-up operations will be less complete than they would be under more optimum circumstances.

An important aspect of the Chukchi polynya with repsect to pollutant transport results from the frequent growth of new ice along the polynya's seaward edge and the consequent possibility that pollutants can be incorporated into this ice and be transported to distant locations. OCSEAP has conducted long-term drift buoy measurements of ice drift off the Chukchi coast {Thorndike, 1977) and also studies of the occasional "break out" events (Reimer, et al., 1979) when Chukchi Sea ice is introduced into the Bering Sea. The results of these studies should be analyzed when considering the possible environmental impact of transport by drifting ice of petroleum originating in this vicinity. From these drift observations, one is led to consider the possibility that the trajectories of pollutants incorporated into ice growing in the Chukchi Sea may include routes into the Bering Sea, onto the Siberian coast or the Arctic Ocean.

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CHUKCHI POLYNYA WIDTH SUMMARY STATISTICS

Point Barrow

	Feb	Mar	Apr	May	June	July	Aug	Sept	Ott
Average Width in km	.2	.6	1	3	4	17	50	>162	>55
Average Standard Dev.	-.4	.8	2	4	6	17	60	133	70
Extreme Max. Width	5	16	14	28	50	105	240	415	368
Average Max. Width	.7	2	4	10	14	38	83	>258	>157
Extreme Min. Width	0	0	0	0	0	0	0	0	0
Average Min. Width	0	0	.02	.03	.2	5	19	68	3
% Days Min. of Zero W.	100%	100%	97%	97%	90%	84%	43%	17%	93%
% Occasions of Zero W.	76%	72%	63%	41%	47%	41%	31%	8%	41%
% Ocasions of >300 W.	0	0	0	0	0	0	0	16%	5%
% Days Measured	60%	78%	82%	78%	64%	47%	24%	27%	56%

TABLE 1

CHUKCHI POLYNYA WIDTH SUMMARY STATISTICS

Point Belcher

	Feb	Mar	Apr	May	June	July	Aug	Sept	Ott
Average Width in km	.2	.4	.8	9	10	25	64	>195	>100
Average Standard Dev.	.5	.8	1.4	10	14	20	59	141	96
Extreme Max. Width	8	14	17	63	64	120	296	560	550
Average Max. Width	1	2	4	26	31	48	95	>283	>241
Extreme Min. Width	0	0	0	0	0	0	0	10	0
Average Min. Width	0	0	0	1	.6	9	40	>112	8
% Days Min. of Zero W.	100%	100%	100%	81%	90%	57%	20%	0%	81%
% Occasions of Zero W.	72%	80%	70%	25%	38X	24%	13%	0%	32%
% Occasions of >300 W.	0%	0%	0%	0%	0%	0%	0%	32%	14%
% Days Measured	60%	80%	84%	78%	59%	42%	18%	26%	54%

TABLE 2

CHUKCHI POLYNYA WIDTH SUMMARY STATISTICS

Icy Cape

	Feb	Mar	Apr	May	June	July	Aug	Sept	Ott
Average Width in km	.1	.4	1	18	32	70	155	256	>132
Average Standard Dev.	.4	.7	3	16	29	43	100	167	86
Extreme Max. Width	3	9	21	77	140	224	304	504	528
Average Max. Width	.5	2	7	44	72	107	199	>337	>245
Extreme Min. Width	0	0	0	0	0	0	40	28	0
Average Min. Width	0	0	0	4	5	36	104	>182	35
% Days Min. of Zero W.	100%	100%	100%	55%	40%	3%	0%	0%	42%
% Occasions of Zero W.	76%	73%	60%	17%	8%	2%	0%	0%	25%
% Occasions of >300 W.	0%	0%	0%	0%	0%	0%	2%	51%	38%
% Days Measured	61%	81%	83%	79%	59%	37%	17%	26%	46%

TABLE 3

CHUKCHI POLYNYA WIDTH SUMMARY STATISTICS

Point Lay

	Feb	Mar	Apr	May	June	July	Aug	Sept	Ott
Average Width in km	.1	.5	1	34	75	141	306	>372	>238
Average Standard Dev.	.2	.9	2	16	54	65	58	154	152
Extreme Max. Width	2	8	20	105	192	400	490	>600	>600
Average Max. Width	.5	2	6	68	143	203	341	>447	>386
Extreme Min. Width	0	0	0	0	0	3	176	84	0
Average Min. Width	0	0	.03	10	25	90	279	>284	>113
% Days Min. of Zero W.	100%	100%	97%	32%	3%	0%	0%	0%	39%
% Occasions of Zero W.	74%	65%	59%	7%	.7%	0%	0%	0%	19%
% Occasions of >300 W.	0%	0%	0%	0%	0%	3%	32%	67%	47%
% Days Measured	61%	78%	81%	81%	56%	36%	14%	23%	43%

TABLE 4

CHUKCHI POLYNYA WIDTH SUMMARY STATISTICS

Cape Lisburne

	Feb	Mar	Apr	May	June	July	Aug	Sept	Ott
Average Width in km	.3	.9	1	14	58	70	>331	>342	>285
Average Standard Dev.	.6	2	2	14	54	43	132	160	144
Extreme Max. Width	8	10	13	140	165	224	595	>600	>600
Average Max. Width	1	3	4	3 6	120	107	>365	>438	>389
Extreme Min. Width	0	0	0	0	0	0	160	200	0
Average Min. Width	0	0	0	1	12	36	>289	>298	>181
% Days Min. of Zero W.	100%	100%	100%	54%	50%	3%	0%	0%	16%
% Occasions of Zero W.	73%	65%	50%	15%	12%	2%	0%	0%	6%
% Occasions of >300 W.	0%	0%	0%	0%	0%	15%	23%	72%	63%
% Days Measured	62%	69%	78%	75%	49%	37%	16%	24%	39%

TABLE 5

CHUKCHI POLYNYA WIDTH SUMMARY STATISTICS

Point Hope

	Feb	Mar	Apr	May	June	July	Aug	Sept	Ott
Average Width in km	.06	.1	1	1	>63	>252	>287	>321	>293
Average Standard Dev.	.11	.3	2	10	83	80	*	*	*
Extreme Max. Width	1	4	13	84	370	>400	545	>600	>500
Average Max. Width	.3	.7	4	24	>169	>318	>370	>407	>357
Extreme Min. Width	0	0	0	0	0	0	250	300	0
Average Min. Width	0	0	0	.02	3	>203	>330	>316	>259
Z Days Min. of Zero W.	100%	100%	100%	97%	77%	1%	0%	0%	13%
% Occasions of Zero W.	90%	93%	68%	49%	33%	3%	0%	0%	4%
% Occasions of >300 W.	0%	0%	0%	0%	7%	51%	29%	87%	92%
% Days Measured	65%	68%	77%	73%	48%	37%	18%	25%	41%

* Standard Deviation not calculatable due to a large number of data points beyond image boundary.

TABLE 6